Fleet Protection Using a Small UAV Based IR Sensor

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1.0 OVERVIEW

A study was performed to define candidate electro-optical and infrared (EO/IR) sensor configurations and assess their potential utility as small UAV-based sensors surveilling a perimeter around surface fleet assets. Requirements were identified, CONOPS defined, sensor spectral bands and attributes derived, sensor performance assessed over canonical Navy littoral environments, at-sea test data collected, processed and analyzed, and technology recommendations formulated. These topics are described below.

2.0 REQUIREMENTS

The following set of requirements was defined:

- Perimeter radius of surveillance area — 30 statute miles
- Update Rate — 20 minutes
- Minimum platform altitude (airspace restriction) — 3,000 ft
- Number of UAVs in simultaneous operation — 5 (threshold); 4 (objective)
- Weight (entire payload incl. electronics) — 25 lbs (threshold); 20 lbs (objective)
- Minimum target signature to detect (see Figure 1) — 0.16 W/sr contrast radiant intensity (measured over 3.4-5 µm spectral band)

Note that the contrast radiant intensity value provided above represents a very low signature, and hence a surface target that will be very difficult to detect at extended ranges. This target was selected to support a conservative analysis of the performance potential of the conceptual implementation presented below.

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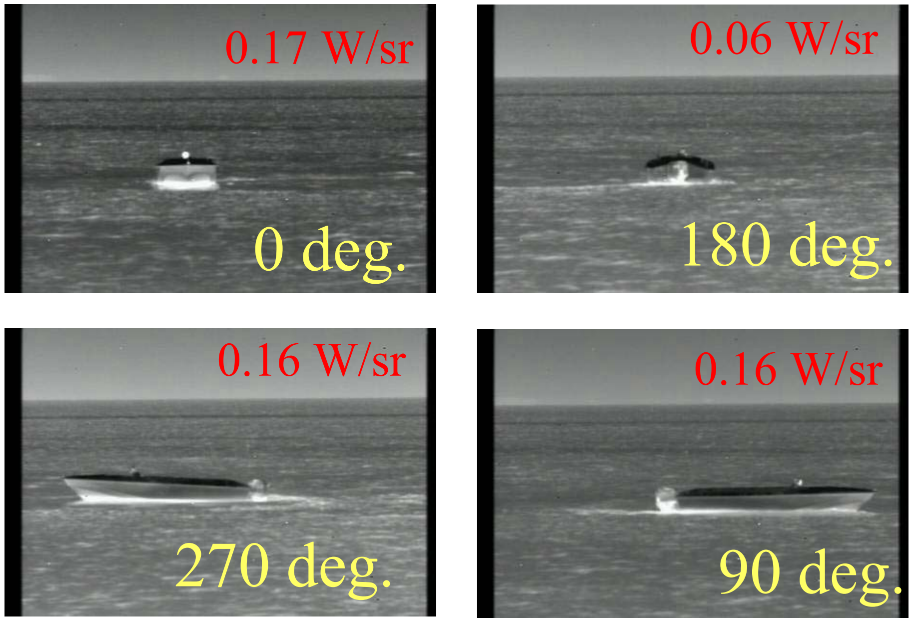

Figure 1: MWIR Signature Measurements of Boston Whaler. Wake was not included in these reported radiant intensity values. 0.16 W/sr was used for subsequent performance modeling and analysis.

3.0 CONCEPT OF OPERATION

Operational Constraints

Various means of surveilling the spaced defined by the perimeter were considered. First, a number of operational constraints were identified:

- The area defined by the 30-mile perimeter radius is large – nearly 3,000 square miles.
- The available UAV platforms are of a class that typically flies at speeds below 100 mph.
- It is desirable for such UAVs to operate at moderate altitudes (e.g., below 20,000 ft). Moreover, cloud cover will reduce the operational availability (i.e., fraction of operating time when requirements can be satisfied) of any EO/IR solution as the altitude increases to thousands of feet.

Limitations in a Down-Looking Sensor Installation

Although down-looking CONOPS were evaluated, the constraints enumerated above led to the conclusion that a down-looking sensor approach, used in conjunction with any contemplated UAV CONOPS, would not be able to provide the required coverage rate. The limitations in available UAV altitude and speed, compared to the very large surveillance area, lead to requirements for a large number (dozens to hundreds) of UAVs even under idealized surveillance coverage operations. For a four-UAV operational objective, each UAV would have to cover greater than 700 square miles in 20 minutes. However, even using aggressive sensor designs coverage rates would not exceed 50 square miles per 20-minute interval at UAV speeds of 80 mph at altitudes up to 16,000 feet. Moreover, at these altitudes cloud cover becomes a limitation on operational availability.

Oblique-Looking Sensor Installation (Recommended Approach)

The analysis therefore focused on an achievable oblique-view scenario wherein the sensor payload can scan through a full 360^{o}, and the UAVs are flown at low altitude around a perimeter, looking out as far as the perimeter range requires at the top of the field of view (FOV) and as far down towards nadir as the sensor FOV permits. Figure 2 illustrates the concept of stepping a sensor FOV through 360 degrees using a belly-mounted turret.

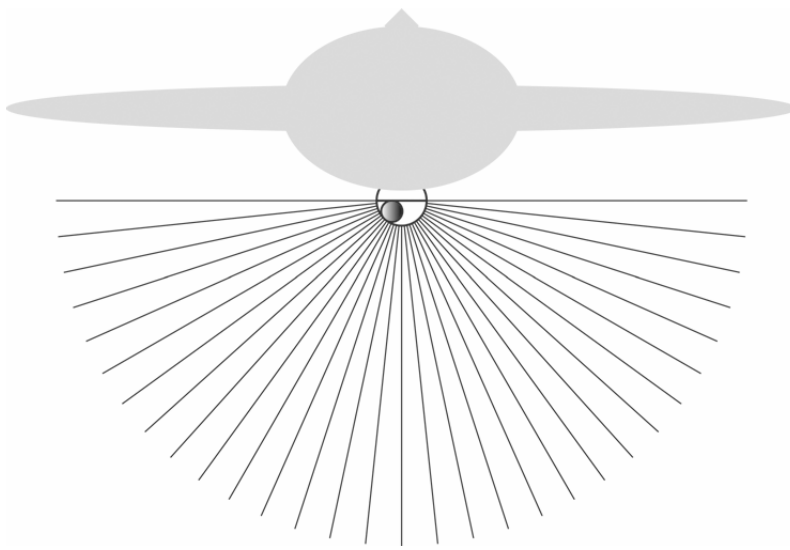

Figure 2: Step-Stare Scanning of the FOV Covers 360^{o}. The optical line-of-sight (LOS) projects outward at a depression angle of a few degrees.

An oblique-looking scenario offers the following advantages over down-looking scenarios:

- Viewing the ocean from an oblique view (i.e., at a grazing angle) projects the sensor's vertical FOV onto a very large footprint on the water, thereby permitting a CONOPS that provides the required update rate using as few as four UAVs.
- The UAVs can fly low, thereby improving operational availability. The UAVs are required to fly at a minimum altitude of 1000 feet to allow observability of small surface vessels at ranges out to 40 miles. Thus, the sensor altitude was assumed to be the minimum allowable platform altitude of 3,000 ft (per the Requirement stated earlier).
- Narrow FOV optics can be employed, simplifying the optical design and improving detection performance at any given range to target. Unfortunately, any CONOPS that is to cover the large area using a highly constrained number of sensors will require long-range performance; this fact leads to larger optics than are contemplated for other missions (e.g., convoy support) using similar small/low UAVs. A narrow FOV sensor, compatible with an oblique-looking approach, at least enables a producible, low-risk sensor design. It also minimizes optical distortion, and increases the sensor's target resolving capability in the azimuth direction.

Number of UAVs

Both 3-UAV and 4-UAV scenarios were modeled and evaluated. A 4-UAV solution offers significantly improved performance and robustness over a 3-UAV scenario:

- **Timeline**: The worst-case update rate out to 30 miles is reduced from 28 to 22 minutes (and is well below 20 minutes over the vast majority of the surveillance space).
- **Range**: The maximum range requirement is reduced from 14 to 12 miles. This may prove pivotal in achieving adequate performance using a modest optic compatible with a small UAV.
- **Robustness**: There is graceful degradation when a UAV is lost or down for service. The surviving three can close in to the 16-mile perimeter, elevate their pointing slightly, and perform the 3-UAV CONOPS. While they won't as robustly detect targets at 30 miles, and the update rate suffers by ~25%, the mission can continue until a fourth UAV can be deployed.

On the other hand, a 4-UAV approach has a few disadvantages:

- **Cost and Logistics**: Four UAVs has greater cost and overhead than 3.
- **Minimum Range**: Four UAVs at 18 miles can see to within 5 miles of the defended ship, vs. < 2 miles with three UAVs at 16 miles. This may not be a disadvantage if perimeter UAVs are not required to cover the area close to the ship. Ship-based sensors may fulfill that mission.

CONOPS Description

Figure 3 illustrates the recommended CONOPS, described below.

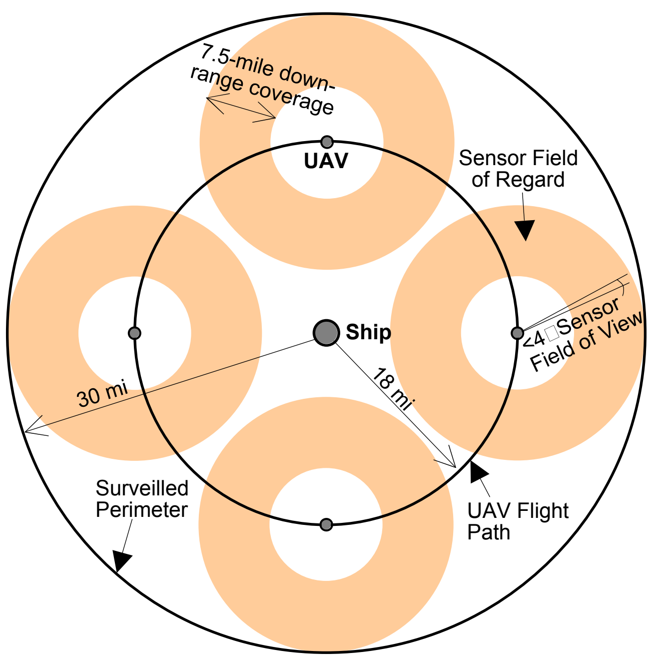

Figure 3: Birds-Eye View of the Recommended CONOPS, Using 3 UAVs with Oblique-Looking Sensors.

One EO/IR camera, having a relatively narrow FOV, is scanned (in step-stare fashion) through 360 degrees, covering from at least 30 miles out to within ~5 miles of the defended ship, as well as along the sensor footprint in front of and behind the UAV. The large “donut” shaped footprint defined by each UAV sensor enables implementations requiring as few as three or four UAVs to achieve an update rate of 20-30 minutes worst-case. Note that the update rate is not constant in time or space, but varies on the ocean surface depending on the location and phasing of the multiple sensors, and on the radial distance of the surface point from the ship.

A simulation was developed and exercised to ensure that realistic coverage rates could be achieved given various sensor and UAV attributes. The results of the simulation experiments showed that the candidate sensors and implementation concepts presented in this paper offer sufficient update rates relative to a 20-minute requirement given UAV speeds of 70 mph. Further, the calculated servo-mechanical bandwidths are low and are believed to be low-risk for development. Figure 4 shows that a 1-Hz step-stare rate provides better than 20-minute updates over most of the 30-mile radius. A 2-Hz rate also was evaluated, and may be feasible for implementation if warranted in terms of the benefit of more frequent updates. A high step rate improves the update rate, but at the expense of data rate and mirror acceleration.

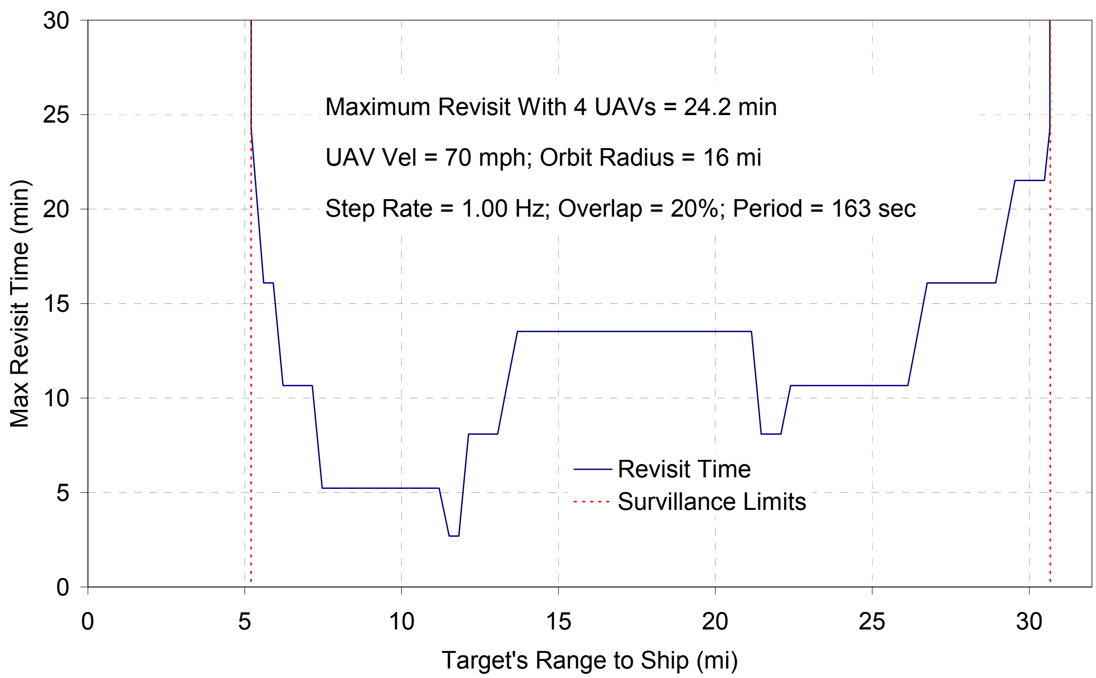

Figure 4: Maximum Revisit Time vs. Range (1 Hz Sensor Step-Stare Rate).

4.0 SPECTRAL BAND SELECTION

Candidate Spectral Bands

Given the long ranges involved in surveilling the required area, it became apparent that a thermal infrared band was the only viable EO/IR approach. The reflected-light spectra (including the visible, near-IR and short-wavelength IR) have fundamental deficiencies in this mission:

- Target contrast on the ocean surface, even in daylight, will be poor at range in many conditions.
- Nighttime and low-visibility conditions cannot be overcome. Active sources are not viable, and low-light technology does not offer the required performance for long-range surveillance.

Thermal imaging offers the potential for high target contrast signatures over many conditions. At grazing angles, the ocean surface generally will have high reflectivity; thus, the background around the target will have an apparent temperature that tracks the sky – which will be low in many cases. Because of their higher emissivity, the hull of the vessel and many typical materials found aboard the vessel will provide contrast to the water and reflected sky even under low temperature differences. Moreover, any heat sources aboard the vessel (e.g., humans, electrical or combustible power sources such as electronics, lights and cigarettes), as well as any observable engine signature and wake, will provide greater contrast signatures than are included in the minimum target signature value given under Section 2.

Table 1 lists five IR spectral bands. The first band shown, "MWIR Reference", is that band in which the signature data shown in Figure 1 was measured. This is a broad medium wavelength IR (MWIR) band. It is not optimal for long-range ocean surveillance due to the inclusion of the CO_2 absorption band (4.2-4.6 µm). It is included as a baseline for the radiant intensity value stated in the Section 1. The contrast radiant intensity values (parameter "J" in the table) of the other bands, which are the subject of the performance evaluation, are computed using the reference band value and a target "graybody" assumption.

Table 1: Radiometric Calculations for Sensor Spectral Bands

					Tnominal:	280	Kelvin	nominal backgnd temp
	MWIR Reference	MWIR Narrow	MWIR Notch	Cooled LWIR	Uncooled LWIR		
Cuton	3.4	3.4	3.4	8.0	8.0	microns	cuton wavelength
Cutoff	5.0	4.2	4.8	10.5	12.0	microns	cutoff wavelength
J	0.16	0.03	0.06	3.17	5.12	W/sr	Radiant intensity
J ratio		0.21	0.40	19.78	32.01	J2/J1	ratio of band intensities
Notch?	*No*	*no*	*yes*	*no*	*no*		
Notch-on			4.15			microns	notch start wavelength
Notch-off			4.6			microns	notch end wavelength
Le	8.48E-01	1.77E-01	3.43E-01	1.68E+01	2.72E+01	W/m^2-sr	excitance
Equiv Area	0.19	0.19	0.19	0.19	0.19	M^2	target effective area

The "MWIR Narrow" band cuts off on the short end of the CO_2 absorption line, having a spectral passband of 3.4-4.2 µm. While the contrast radiant intensity is reduced compared to the reference band, the transmission is greatly improved.

The "MWIR Notch" band uses a notch filter to take out the background flux in the low-transmission regions from 4.2-4.6 µm and above 4.8 µm. While the contrast radiant intensity is reduced somewhat compared to the reference band, the transmission is greatly improved.

The "Cooled LWIR" is assumed to be a long wavelength photodiode based device, offering very high sensitivity, but expensive relative to all other tactical IR sensors.

The "Uncooled LWIR" is assumed to be a microbolometer array. Uncooled detectors are somewhat inferior in sensitivity, and suffer from long thermal time constants. However, the technology is attractive due to its low price and low overhead (size, weight and power) achieved by eliminating the cooler.

Sensors for all bands except the uncooled LWIR are assumed to be cryogenically-cooled photodiode-based focal plane arrays (FPAs) of a configuration such as is used in other surveillance and situational awareness missions (e.g., 640 x 512 or 1K x 1K pixels).

Atmospheric Transmission (MWIR vs. LWIR)

The candidate spectral bands were run through a Visual Basic/Excel program that computes band-averaged atmospheric transmissions for a specified sensor-target range (in this case, 12 miles) for each of the 1,872 cases contained in the Navy Littoral database.

Figure 5 shows the results, rank ordered from highest to lowest path transmission individually for four spectral bands (note that the atmospheric cases are ordered differently for each scenario).

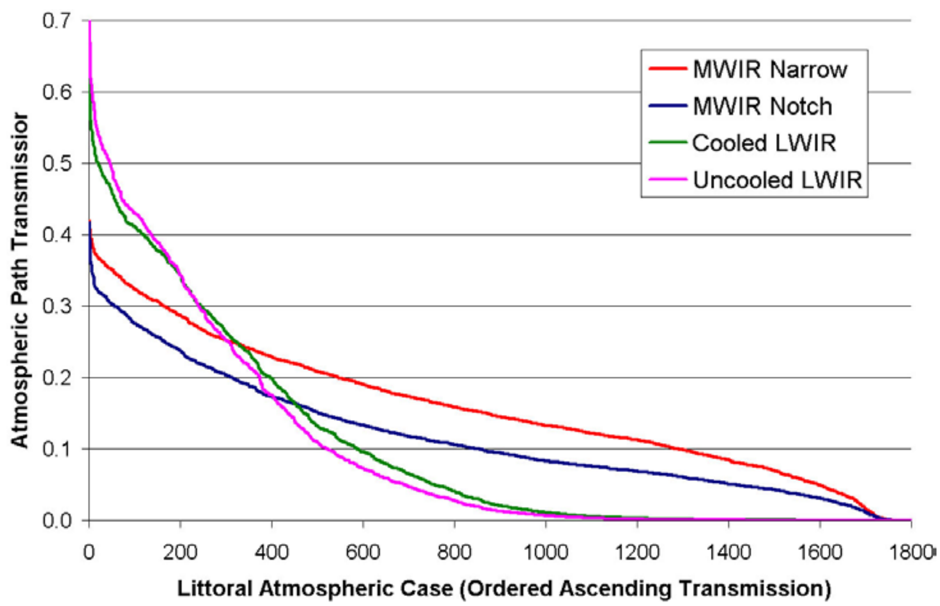

Figure 5: Littoral Atmospheric Path Transmission for MWIR Sensor at 14-Mile Range.

Required Sensor Performance

Using the previously described parameters J (contrast radiant intensity), R_{max} (maximum required detection range), and τ (distribution of atmospheric transmission values), the distribution (over littoral atmospheres) of required sensor performance levels can be quantified. As this surveillance problem is tantamount to that of an infrared search and track (IRST) system, the figure of merit employed is that used for IRSTs – noise equivalent irradiance (NEI). NEI is shown on the right in the following equation describing the required performance for each transmission case:

$$\frac{J \cdot \tau(R_{\max})}{R_{\max}{}^{2}} = SNR_{T} \cdot NEI \tag{1}$$

The other parameter shown on the right side of Eq. (1) is SNR_T (threshold signal-to-noise ratio required to detect the target). The product of SNR_T and NEI is herein referred to as the “required NEI”.

Figure 6 shows the distribution of required NEI over the littoral atmospheres for the graybody target. The NEI requirement spans a much wider range over the atmospheric cases in the LWIR than in the MWIR.

In absolute terms, the required performance (against the very low-signature assumed target) is challenging in all cases. NEI values below 1E15 W/cm^2 (MWIR) and 1E13 W/cm^2 (LWIR) represent the state-of-the-art for infrared sensor systems of this class. The MWIR is more robust in the worst atmospheric cases, whereas the LWIR approaches physically unrealizable performance levels at approximately the median atmosphere. ***Because of the atmospheric robustness (especially in the presence of high humidity, a common operational situation), an MWIR sensor approach was adopted for this application***.

It is important to emphasize that (1) NEI cannot be directly compared across spectral bands, as the realizable NEI levels of a LWIR sensor are considerably higher (worse) than those for a MWIR sensor; and (2) the conservative target signature assumed favors longer wavelengths, whereas any actual presence of wake or active heat sources will add signature to all bands, but will tend to boost MWIR performance more rapidly than LWIR performance. Point (1) is addressed quantitatively in the following section.

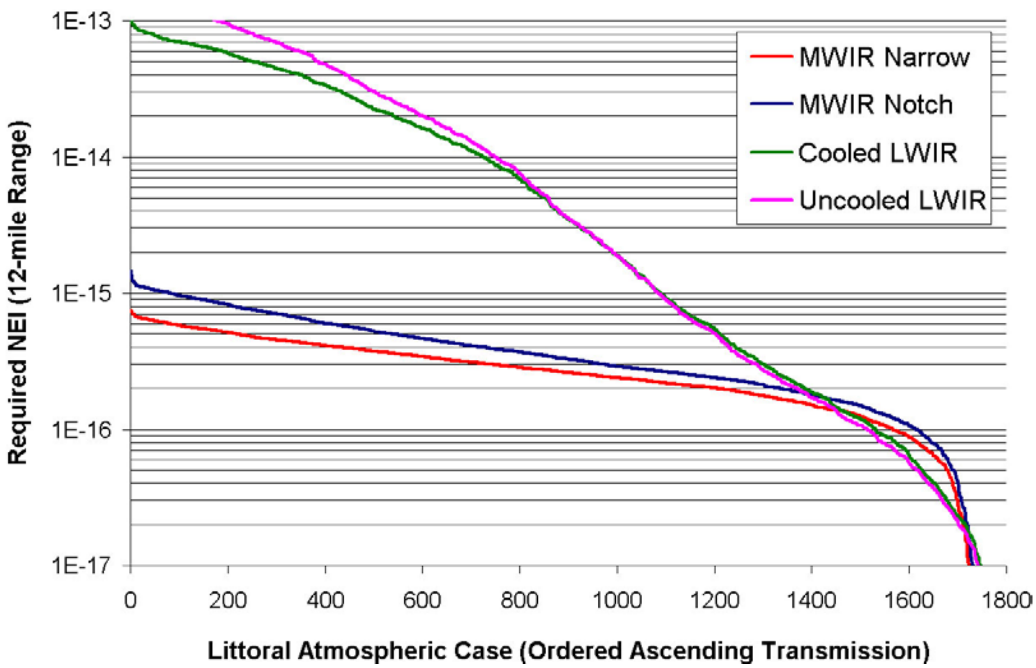

Figure 6: Required NEI (i.e., sensor NEI * SNR_T) Over the Navy Littoral Atmospheres at 12 Miles Against the Low-Signature Assumed Target. Note that NEI For different spectral bands cannot be directly compared.

5.0 SENSOR SPECIFICATIONS AND PREDICTED PERFORMANCE

Focal Plane Array Attributes

Both 640 x 480/512 and 1K x 1K pixel formats were considered. With optics selected for equivalent resolution, the 1K x 1K format offers a larger field of view (FOV). For CONOPS involving a fixed sensor FOV line of sight – that is, where the field of regard (FOR) equals the FOV – the larger FOV of the 1K x 1K provides a significant benefit to coverage and update rate. However, as described in the Concept of Operations section, the only feasible means of covering the large area is to scan or "step-stare" the FOV across a large FOR. For such scenarios, the coverage and update rates are less sensitive to FOV changes.

Conversely, the advantages of a smaller 640 x 480/512 format are smaller, lighter, lower-power packages. Notably, the cooler is smaller and lower power. 640 x 480 (LWIR) and 640 x 512 (MWIR) FPAs are available in 20-µm pixel formats; the 1K x 1K cooled MWIR FPA is only known to be available in a 25-µm pixel. The smaller format combined with the smaller pixel of the 640 x 480/512 FPA provide a significant reduction in size and weight throughout the sensor (i.e., optics, servos, and cooler). ***This is of paramount importance for installation aboard a small UAV, and is the determining factor in selecting the 640 x 512 format***. 640 x 512 FPAs also are considerably less expensive that 1K x 1K FPAs.

Optics Attributes

The smallest, lightest, and lowest-performance optic considered was a 62-mm effective clear aperture, 150-mm equivalent focal length (EFL), f/2.3 optic. Four variations to this design were considered, ranging up to the largest and highest-performance: an 87-mm aperture, 200-mm EFL f/2.3 optic. In between these two design points were two 75-mm aperture designs of varying EFL. Nominally, the requirement is stated simply as a 75-mm ("3-inch") aperture requirement.

Figure 7 plots the modeled NEI results for the two bands (MWIR and LWIR) at the 200-mm focal length. These sensor NEI predictions are overlaid on the applicable NEI transmission plots given in Figure 6. This figure confirms that, in order to achieve robust performance over a broad set of atmospheric conditions, the MWIR is the preferred spectral band.

Note that an increase in target signature (due to presence of wake, heat sources onboard the vessel, a larger type of vessel, or a closer range than 12 miles) will relax the required NEI curves (i.e., shift them upward), thereby increasing the number of cases satisfied by each sensor configuration.

Note also that this plot is for the maximum range in the surveillance space. Ranges much closer to the UAV and sensor also must be covered. In general, the LWIR band gains a relative advantage as the range to target is reduced. However, the system design must account for the most difficult set of conditions, which occur at maximum range.

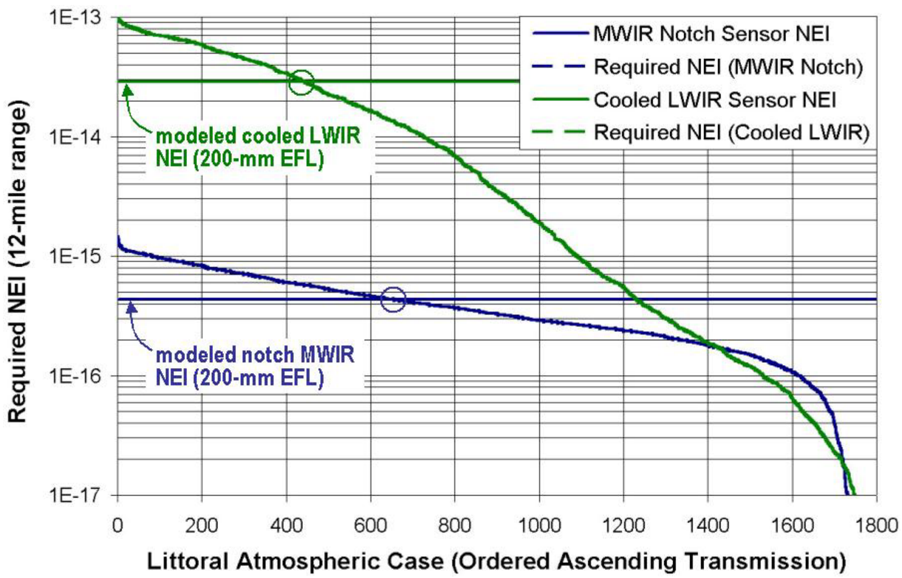

Figure 7: Modeled NEI*SNR$_T$ for MWIR and LWIR Sensors, Overlaid with the Required NEI of Figure 6.

Performance Summary

The following points summarize the sensor definition and performance modeling:

- The proposed cooled MWIR sensor (notch filter, 150-200 mm FL, ~3" optic) will detect targets in many scenarios.
  - Small targets in favorable atmospheres out to 12 miles.
  - Brighter targets (larger vessels, wake, observable heat sources from engine and onboard).
- Performance of practical sensor configurations on small UAV will be challenging at 12 miles.
  - For small, low-signature targets.
  - In poor atmospheres.
- Despite performance challenges, a viable payload has been conceived for use on small UAVs.
  - CONOPS requires only 3-4 UAVs for wide-area coverage.
  - Thermal IR provides day/night capability.

6.0 FIELD TEST AND PROCESSING RESULTS

Description of Test Event

In March 2005 a test was conducted at Point Loma (San Diego, CA). Data was collected in the morning, afternoon, and at night. The tests were conducted under benign atmospheric conditions except in afternoon solar clutter. The test involved three sensors – two MWIR sensors and a color daytime visible sensor – situated at a fixed land site approximately 300 ft above sea level (ASL) and looking in a westerly direction out to sea. One of the MWIR sensors had comparable performance to the objective sensor design described previously, and is the focus of the analysis presented below.

The sensors collected image data of a small surface vessel located at various distances out to sea. Figure 8 shows provides two views of the boat and key physical dimensions. It was a small harbor patrol boat, having a reflective hull and cabin. This target was expected to have a low thermal signature.

Harbor Patrol Boat Dimensions:

- **Length: 24 ft.**
- **Beam: 8 ft.**
- **Cabin height above waterline: 6.5 ft.**
- **Deck height from waterline: 2.5 ft.**
- **Cabin height from deck: 4 ft.**
- **Cabin length: 6 ft.**
- **Cabin width: 6 ft.**
- **Deck length aft of cabin: 12 ft.**
- **Deck length forward of cabin: 6 ft.**

Figure 8: Harbor Patrol Boat Target Tested Near San Diego in March 2005.

The boat-to-sensor range was varied from 4 to 14 nautical miles. ***Note that distance measurements in this section of the paper are given in nautical miles***. Data collected at 10 nmi (= 11.5 statute miles) is representative of the detection range requirement for this mission, as described earlier in the paper.

Test Observations

During testing there were pronounced variations in target observability, as the boat heaved in waves. Observers were visually able to find the boat using the MWIR sensor of interest as far out as 14 nmi, and virtually continuously (except when occluded by waves) at 10 nmi. Figure 9 shows eight image chips collected with the MWIR sensor viewing the boat target at 12 nmi in the morning test.

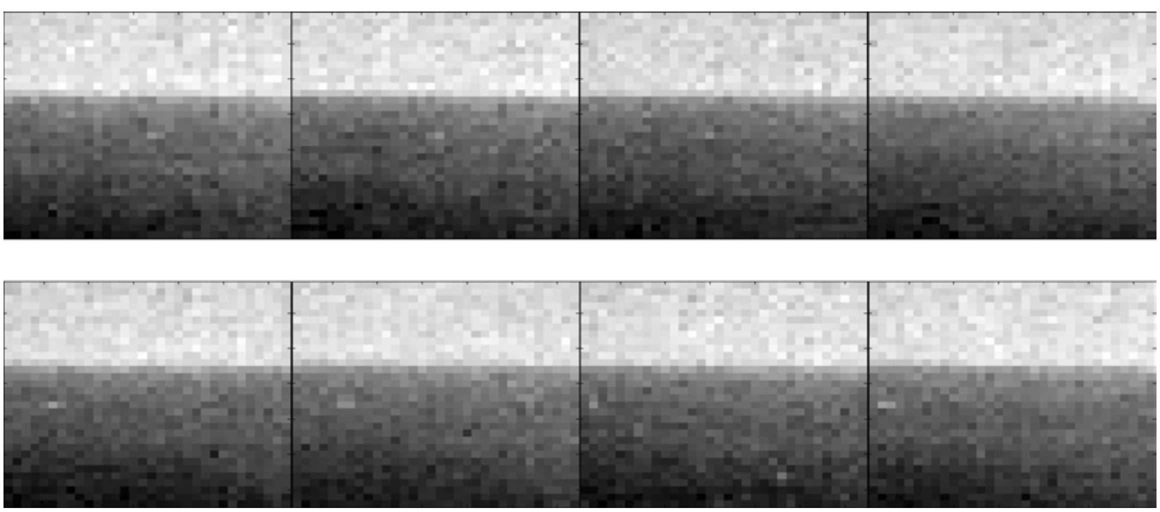

Figure 9: Zoomed, Cropped, Non-Sequential Images of the Boat Target at 12 nmi Collected in the Morning.

Approach to Signal Processing

For the analysis of the Pt. Loma test data, a Northrop Grumman software tool called ATI was used. The heart of ATI is an anomaly detector known as the triple-window filter (TWF), developed as part of a mine detection program. The TWF applies a spatial filter matched to the target size, and then estimates the standard deviation of the residue. The primary metric is the signal-to-clutter ratio (SCR). A block diagram of the operation of the TWF is shown in Figure 10.

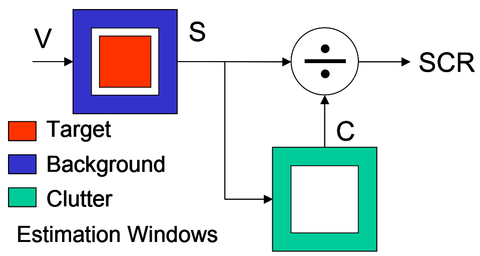

Figure 10: Triple Window Filter (TWF).

To approximate performance of the objective sensor (at the low-end, i.e., 150-mm EFL f/2.3), 20-frame averages were generated and used. TWF coefficients were chosen for best performance against an unresolved target, subject to proximity of the horizon. ATI then was run, generating a list of detections and SCR values for each 20-frame-averaged sequence. The detection corresponding to the known location of the target was separated from the other detections.

The effort focused on the 10 and 12-nmi MWIR data. Figure 11 shows the ATI interface and an image from the 12-nmi morning data set. Blue circles indicate false detections. The yellow box indicates the boat detection. Although there are a significant number of false detections, most do not persist in subsequent 20-frame averages; thus, most false detections may be eliminated using a track processor.

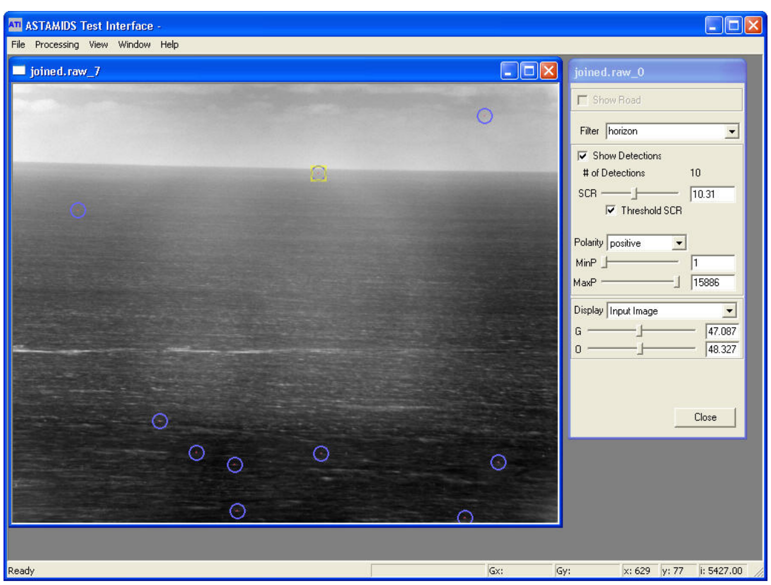

Figure 11: Example Detections at a 12-nmi Range for a 20-frame Average Taken from the 250-mm Sensor.

Shortcomings of Test & Analysis Approach

The ATI software built into ATI makes use only of integer tap weights in the TWF filters. Use of integer tap weights built into the TWF, rather than fractional matched-filter tap weights, is predicted to reduce 12-nmi target SCR by 27%.

Target proximity to the horizon also had a significant (though unquantified) impact on SCR. Horizon clutter, preconditioned by TWF, "bled" into the target window. Moreover, the filters were "flattened" in elevation to reduce exposure to the horizon, compromising target detection strength. Horizon effects were most pronounced in the 12-nmi data, less so in the 10-nmi data.

Finally, the grazing angle of the sensor-to-target geometry also reduced target observability. The boat heaving obscured part of target behind waves frequently. An airborne perspective will in general increase apparent target area, and provide an improved perspective of surface targets in the presence of waves.

10-nmi Results

Both SCR and SCR rank were analyzed for the 10-nmi range. SCR rank is the rank-ordered position of the target SCR relative to the SCR of all detections in each sequence. From the SCR rank a "probability of detection" (P_d) can be approximated, and resulting false alarm rate investigated. For the 10-nmi case, P_d was set to 0.9. The target rank at the 90th percentile falls to 30. Thus, a SCR threshold that detects 90% of the targets at 10 nmi would produce roughly 30 false detections per sequence.

Figure 12 plots the top 30 detections vs. x-y position in the image for each of the 38 10-nmi sequences processed. Despite a relatively high false alarm density over the entire frame, few false detections occur below the horizon in the vicinity of the target, or for that matter anywhere in the unresolved target region.

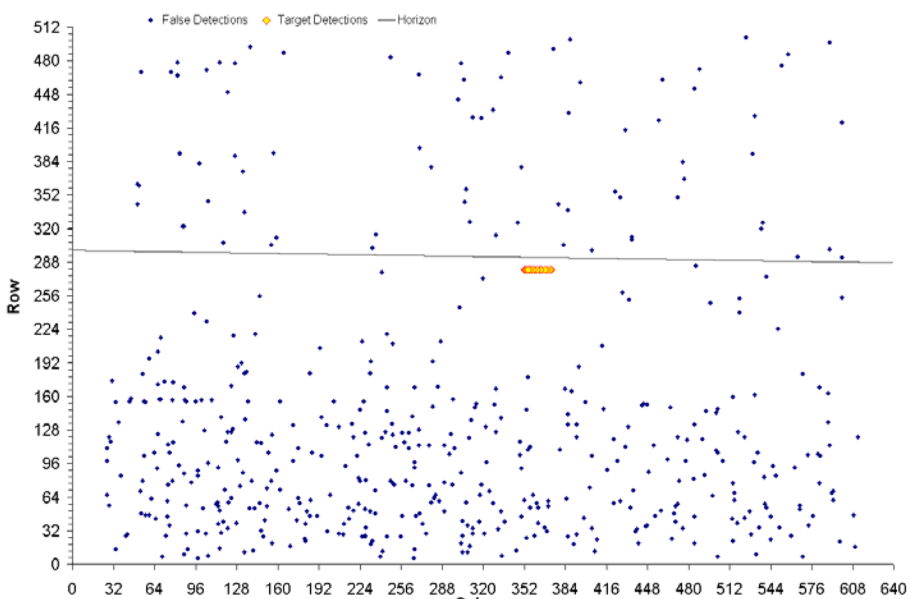

Figure 12: Top 30 False Detections (Blue Circles), Corresponding to P_d = 0.9, in Each of 38 Sequences (10-nmi Data, 20-Frame Averages). The target detections are shown as red/yellow diamonds.

Comparison of 10 and 12 nmi Results

Figure 13 plots target SCR vs. target detection rank for both 10 and 12-nmi target detection sets. Most target detections having SCR > 10 (all of which were in the 10-nmi range set) were either first or second in rank (i.e., strongest detection in the image).

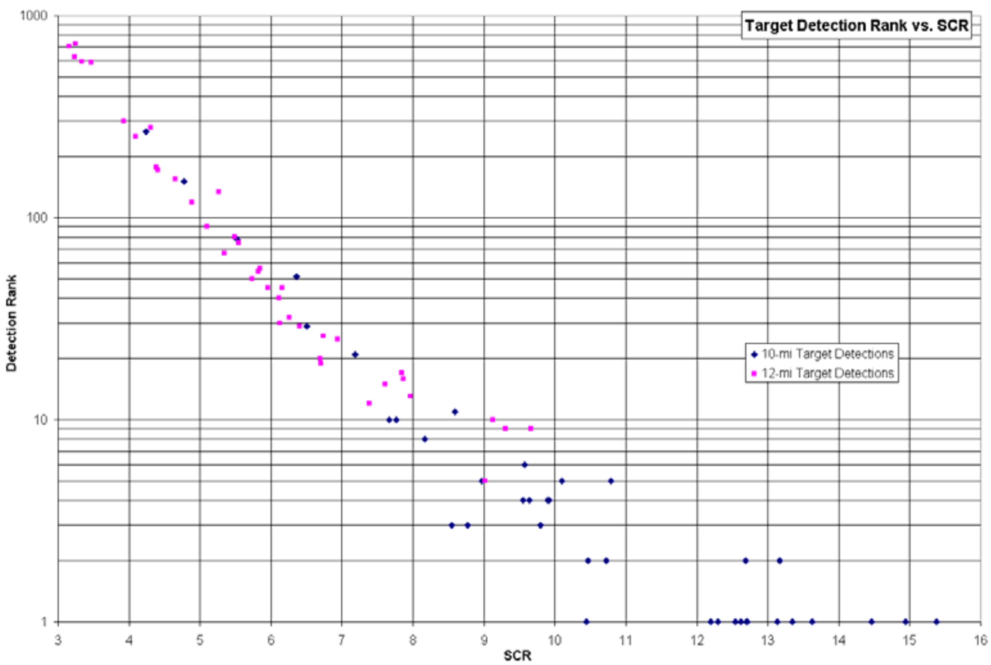

Figure 13: Target Signal-to-Clutter Ratio Histogram (10 and 12-nmi Ranges).

Summary of Data Processing and Analysis

The following points summarize the results of processing and analysis performed using the boat target data collected at Point Loma:

- The 250-mm f/4 MWIR sensor demonstrated a detection capability close to the required performance of the objective sensor design.
  - The 14-nmi data did not reveal the target adequately for processing.
  - The target was detectable in the 12-nmi data, though at SCR values that led to relatively high false alarm rate.
  - The target was robustly detectable in the 10-nmi data, using a threshold sufficiently high to suppress most false alarms. As stated earlier, 10 nmi = 11.5 statute miles, which is close to the objective sensor detection range requirement of 12 mi.
- No benefit was given to the potential for track processing.
  - A tracker would associate detections over two or more looks, rejecting clutter that does not persist and declaring persistent detections as targets of interest.
  - Track processing performance increases with update rate; thus, a step-stare rate > 1 Hz (rate required simply to achieve the minimum operational update) may be beneficial.

- Target detection performance was reduced due to proximity to the horizon. An airborne sensor, flying at thousands of feet ASL, will not have the horizon in its FOV when viewing the desired down-range swath (~5-13 miles slant path).

7.0 SUMMARY AND RECOMMENDATIONS

The thermal IR was determined to be the only viable EO/IR technology for the mission of airborne surveillance supporting fleet protection. Among IR configurations considered, only the MWIR offers robust performance at ranges consistent with the assumed requirements, constraints and CONOPS.

Achieving the level of sensor performance required against a particular small, cool surface target at up to 12 miles standoff is deemed challenging, but realistic, for an objective sensor providing net performance comparable to or better than the sensor tested at Point Loma. When the target signature is augmented by other contributors – ocean wake, onboard/offboard heat sources, larger or more emissive surface craft, and varying diurnal and weather conditions – detection performance will increase rapidly.

Detection performance improves quickly as range decreases. Because there is no means for even a highly capable (i.e., informed and fast) adversary to breach the surveilled space without being observed multiple times by one or more of the UAV sensors (at ranges significantly closer than the maximum range), the CONOPS defined in this paper is fundamentally sound in providing surveillance over an extended space in support of platform protection. Low-signature surface targets at or near the maximum range of 30 miles from the ship that do not eventually close on the ship probably are of marginal interest or threat.

The following recommendations are made:

- Pursue a two-axis stabilized payload maintaining oblique-view LOS pointing.
- Employ a state-of-the art, medium-format (e.g., 640 x 512), cooled MWIR sensor solution.
- Employ an optic with an effective clear aperture of approximately 3 inches and a focal length in the range of 150-200 mm.
- Collect and evaluate additional thermal signature data of diverse surface vessels and payloads.